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**Mental and Emotional Strain Elicited by Inadequate Temporal Structures in Human-Computer Interaction**

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As a consequence of the introduction of information technology at all kinds of workplaces, the nature of the organization of work as well as the nature of the tasks has changed. With the use of computers, "virtual" office desktops, filing cabinets, drawing boards, measuring instruments, and other devices are provided to the worker. Without leaving his workplace, the human operator is able to switch between tasks, to use different tools, to get information, and to communicate with other people. Therefore, all steps necessary to complete a task can be done by a single person sitting in front of a computer screen. There is no need for additional personal, technical, or organizational assistance and there will be no time delay caused by organizational settings. Thus, for the computer user, work density is highly increased, and the temporal structure of the human-computer dialogue becomes very influential on the user's strain.

The temporal features of computer work therefore have to be regarded as being a prominent source of stress, because the computer can either rush or inhibit the user's work flow. This was demonstrated by two of the laboratory studies mentioned in Wolfram Boucsein's contribution to this workshop. In both experiments reported (cf., Schaefer, Kuhmann, Boucsein & Alexander 1986, Kuhmann, Boucsein, Schaefer & Alexander 1987), system response time (SRT), being the main determinant of the temporal structure of the human-computer dialogue was systematically varied. According to the requirements of a highly controlled laboratory study, simple visual detection tasks (STERZINGER lines) were used, and the SRTs occurred only between successive tasks. Consistently, the results of both studies showed a clear relationship between temporal features of the human-computer dialogue and the user's stress responses.

However, the results suggest that two different sources of stress have to be considered:

(1) Long SRT must be regarded as being mainly as a source of emotional stress, due to the inhibition of the user's work flow.

(2) On the other hand, short SRT must be regarded mainly as a source of performance related stress, probably due to a rushed work flow.

Obviously, short SRT led to a deterioration of information processing, causing the detection of the targets to be more difficult with short than with long SRT. To cope with this deterioration, the users increased their effort, which was reflected by the increase in their physiological responses.

- *Are increased physiological responses to short SRT due to mental load, or to motor activity?* -

With short SRTs, more tasks have to be performed within the same time, compared to long SRTs. As a consequence, the observed physiological effects might probably have been caused by higher
motor activity due to an increased task performance, but not by coping with a deterioration in information processing.

Therefore, a series of two experiments was performed, where motor activity was varied to exclude any influence of this factor on the results mentioned above. In these particular experiments (Schaefer, Kohlisch & Kuhmann 1991, Kohlisch & Schaefer, submitted), rhythmic keystrokes were required to keep a moving target within a limited range on the computer screen at different speed levels as the primary task, and mental arithmetic at two different levels of difficulty was used as a secondary task.

Only if the keystroke intervals were shorter than 360 ms, an influence of the motor activity on the physiological variables could be observed. Therefore, it can be concluded that all physiological effects had to be attributed to the variations in the mental task, if less then 3 keystrokes per second are required. This is exemplified by the number of spontaneous skin conductance responses, being the indicator of emotional arousal (cf., Boucsein 1992). For this variable, the difference scores to the expected mean are shown in figure 1.

- figure 1 -

In these experiments it could be demonstrated that physical activity affects the physiological stress responses only at a high level of movement frequency. Therefore, it can be concluded that effects of motor activity on physiological stress indicators can be neglected in typical computer work (if no extensive type writing is demanded). Any observed physiological changes in such studies have to be attributed to coping with other sources of stress.

*- Have long and short SRT to be regarded as being two different sources of stress? -*

The studies mentioned by Wolfram Boucsein pointed out that very short SRT as well as very long SRT could increase the user's strain in two different ways. On one hand, it was hypothesized that long SRT acts mainly as an emotional stressor, because the user's work flow is interrupted by SRT. On the other hand, it was assumed that the user is rushed and his information processing is deteriorated, if SRT is short. Taken both sources of stress together, one should expect that the user's strain might be lowest, if SRT has a medium duration.

For the specific visual detection task as used in these experiments (Schaefer et al. 1986, Kuhmann et al. 1987) long SRT had a duration of 8 s, and short SRT had a duration of 2 s. SRT of 5 s duration therefore can be considered as being a good medium value for the particular task.

Therefore, another study was performed using the same tasks to demonstrate that the user's strain is lowest with SRT of medium duration (Kohlisch & Kuhmann, submitted). Three SRT conditions (2, 5, and 8 s) were realized as between-subjects-factors. With respect to the results of the 2 and 8 s SRT conditions, this study can be considered as a replication of the earlier investigations, since blood pressure, error rate, and pain symptoms were significantly higher with 2 s than with 8 s SRT.

- figure 2 -

Taking all SRT conditions into account, error rate, number of keystrokes per task, and frequency of non-specific skin conductance responses, were lowest with 5 s SRT, as shown in figure 2. Additionally, for the latter two variables, U-shaped curves with a minimum at 5 s SRT could successfully be fitted to the data in regression analyses, but these curves were not symmetrical. Therefore, also the results of the earlier studies (Schaefer et al. 1986, Kuhmann et al. 1987) were according to the asymmetric U-shape model.

- figure 3 -

On the other hand, blood pressure was highest with 2 s SRT and task completion time was shortest with 8 s SRT, as shown in figure 3. For these variables, linear functions could successfully be fitted to the data in regression analyses.

It can be inferred from error rates and longest task completion times that mental processes involved in task solution were deteriorated with 2 s SRT. The users tried to cope with this deterioration, which was reflected by an increase in blood pressure and pain symptoms in that condition.

With 5 s SRT, the level of arousal could be regarded as being optimal for high performance efficiency. This was reflected by normal blood pressure on one hand, and relatively short task completion times and lowest error rate on the other hand.

With 8 s SRT, the level of arousal was too low, which was reflected by low blood pressure. To cope with the lack of stimulation while waiting for the end of the SRT, afterwards the users increased their speed in task performance. But as a consequence, the error rate was higher than with 5 s SRT.

As can be inferred from the error rates throughout all studies mentioned here (Schaefer et al. 1986, Kuhmann et al. 1987, Kohlisch & Kuhmann, submitted), task related information processing is obviously deteriorated if SRT has a very short duration (2 s, for the particular task). With SRT being somewhat longer (5 s), such a distraction is not discernible (cf., figure 2). Therefore, short SRT has to be regarded as being a specific source of performance related stress, causing a rushed work flow and leading to a deterioration of information processing, because the detection of targets was more difficult, as compared to SRT of medium duration. To cope with this source of stress, the users increased their effort referring to accuracy. This is indicated by prolonged task completion times, as well as by a physiological effort component that is reflected by higher blood pressure and more pain symptoms as a consequence of higher muscular tension with short SRT, as compared to longer SRTs (cf., figure 2).

On the other hand, the responses to very long SRT (8 s, for the particular task), might be explained following the suggestions of Miller (1968): The user and his attention are ordinary captive to the screen until he receives a response to his inquiry. If long SRT forces extended captivity, the user will feel annoyed and disrupted, and his work pace and motivation to work will be reduced. Therefore, long SRT has to be regarded as being a second source of stress, increasing the emotional arousal as a consequence of the inhibition of the user's work flow. The observed changes support these suggestions, since error rate (cf., figure 3) and pain symptoms were higher with 8 s SRT than with 5 s SRT, but lower compared to 2 s SRT.

Best performance, lowest frequency of non-specific skin conductance responses, and lowest pain symptoms were found to be associated with SRT of medium length, which has been 5 s for the specific task used in our studies. Therefore, user's strain was related to SRT duration in a U-shaped function, with a minimum about 5 s SRT (figure 2).

*- Are stress responses to inadequate temporal features of the human-computer dialogue also found in performance of complex tasks?*

Whereas 5 s SRT appeared to be the optimum for the very simple visual detection task used in the experiments mentioned above, SRTs of different duration might be more appropriate for other, more complex tasks with different cognitive demands. Therefore, optimal temporal structures for human-computer interaction may have to be determined empirically for each kind of task.

Instead of traditional laboratory research practices' time estimation techniques can easily be applied when prototyping a newly developed software that allows the users to set up the SRTs themselves (cf., Kohlisch 1992). It can be expected that the users will consider all task characteristics and cognitive demands appropriately by intuition. But according to the circumstances of working on a task, unknown biases due to every estimation method have to be considered.

Concerning this problem, a study was performed to investigate which time estimation method will fit the software designer's intentions best (Kohlisch 1992). Additionally, the results of this study gave an impressive demonstration of the stress inducing properties of inadequate time structures in human-computer interaction.

In the experiment mentioned, four different time estimation techniques were compared to decide which method is most suitable to determine the optimal SRTs, using performance, subjective, and physiological criteria. Simulated airport check-in tasks were used, each one consisting of a sequence of four working steps, all separated by SRTs. The total SRT per task (time for data retrieval, connection to mainframe, etc.) was adjusted to 13.42 s. The subjects had to distribute this total SRT on the four steps of the task, using one of the time estimation techniques.

It was expected that an optimal partition - or the "best" time structure - would be obtained, if a graphic tool is provided to the subjects for the distribution of the total SRT on the four steps of the task. The subjects were trained to use the time estimation methods for two hours. Afterwards they received a trial of 25 min duration, where they had to select their own SRT partition. This partition was used as the independent variable for the following test trial of another 25 min duration.

- figure 4 -

Every time estimation method yielded a significantly different partition of the total SRT (cf., figure 4). Compared to a reference trial, partition similarity was obtained mostly when the graphic tool was provided (partition 4), because the subjects kept the distinct proportions of the four partial SRTs according to the reference trial, while the other time estimation methods failed to do so.

Subjective measures showed no differences among the four estimation methods. Therefore, it can be assumed that the overall mental workload was high in all conditions. Poorest performance with highest error rates was observed under partition 1, while partition 4, which was obtained using the graphic tool, yielded best performance.

Comparing phases of work and rest, only slight differences in phasic physiological activity between both kinds of situations could be observed with partition 4, while the other partitions yielded bigger differences between the situation. These differences had to be regarded as an increase in the physiological stress indicators. Therefore, partition 4 can be regarded as being a "good" time structure with "optimal" SRTs, while the other partitions have to be regarded as "bad" time structures in human-computer interaction.

Furthermore, the importance of the temporal structure of the human-computer dialogue in subjective stress perception could also be demonstrated in a field study at the central typing office of a bank (Kohlisch, Kuhmann & Boucsein 1991). The results of this field study were according to the results of the other studies mentioned here.

In conclusion, SRT has to be regarded as being one of the most prominent sources of stress in work with computers. Both mental and emotional consequences of inadequate SRTs are reflected by physiological, subjective, and performance changes that have to be interpreted as being the responses to stress. To increase the user's efficiency, to minimize his strain and to avoid the additional cost of error correction, optimal SRTs for the particular task should be evaluated and applied to ergonomic software.

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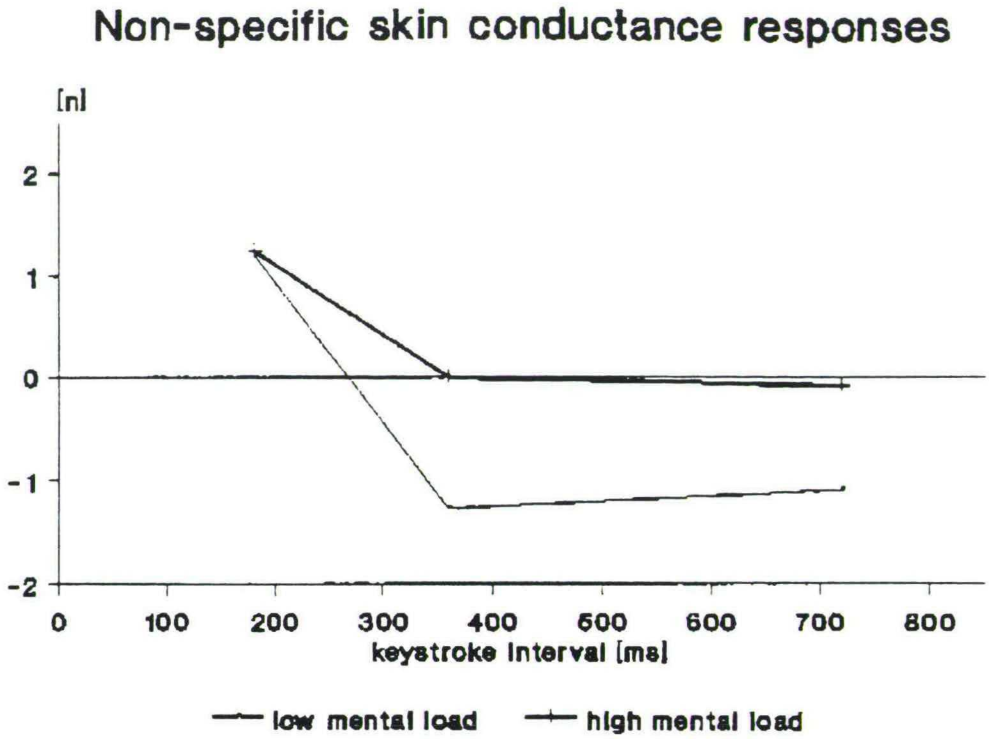


Figure 1

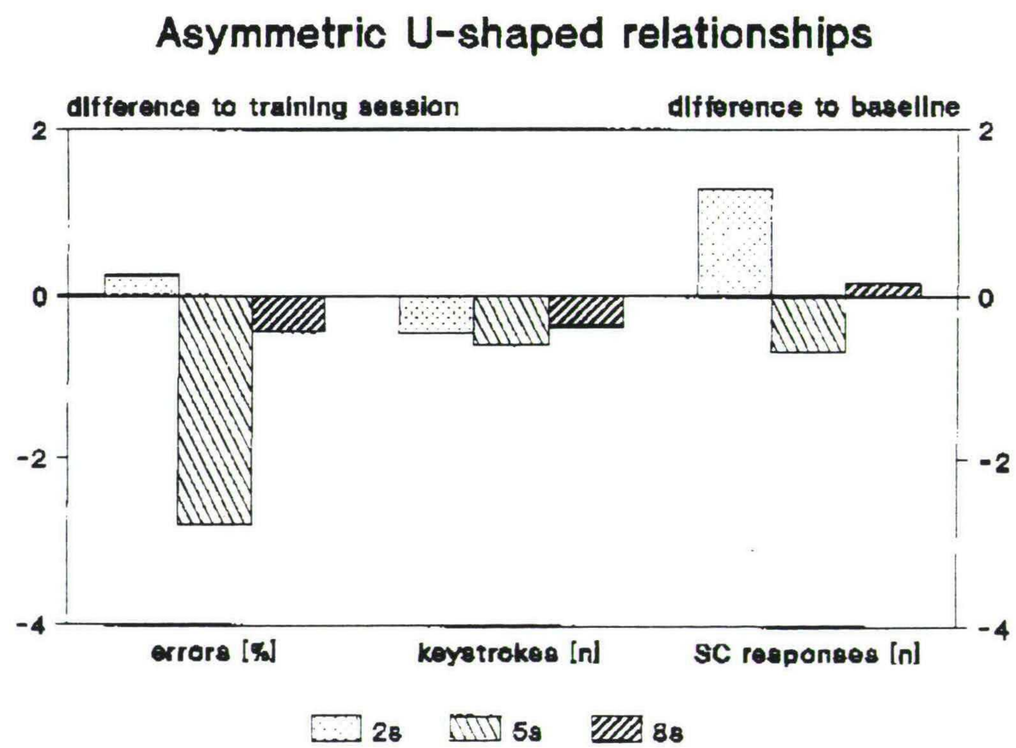


Figure 2

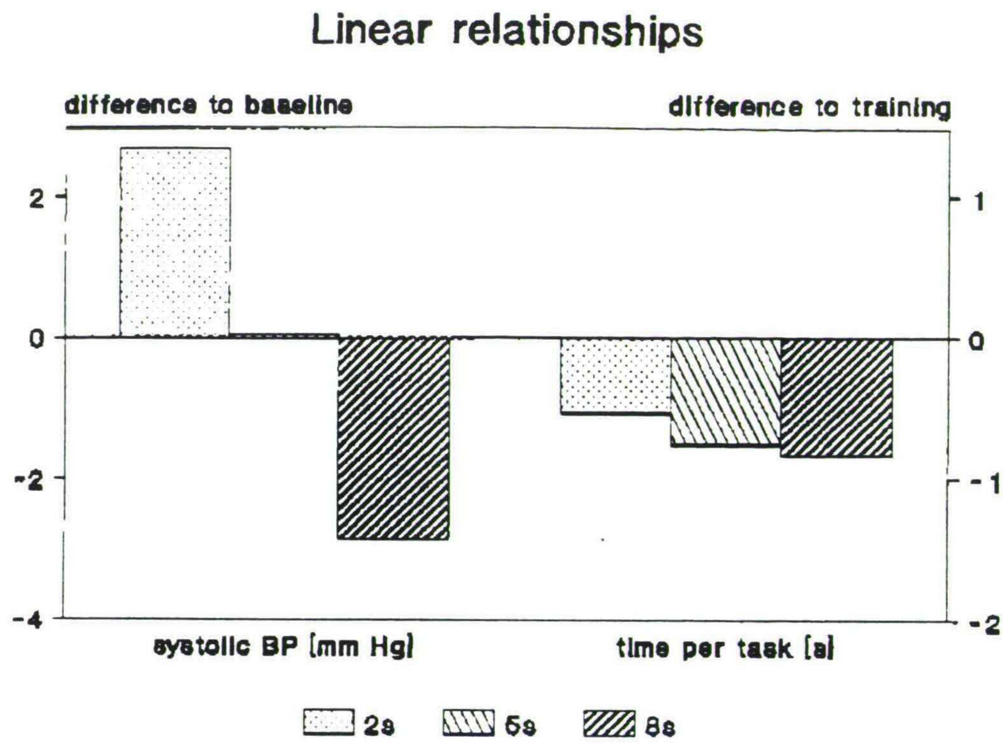


Figure 3

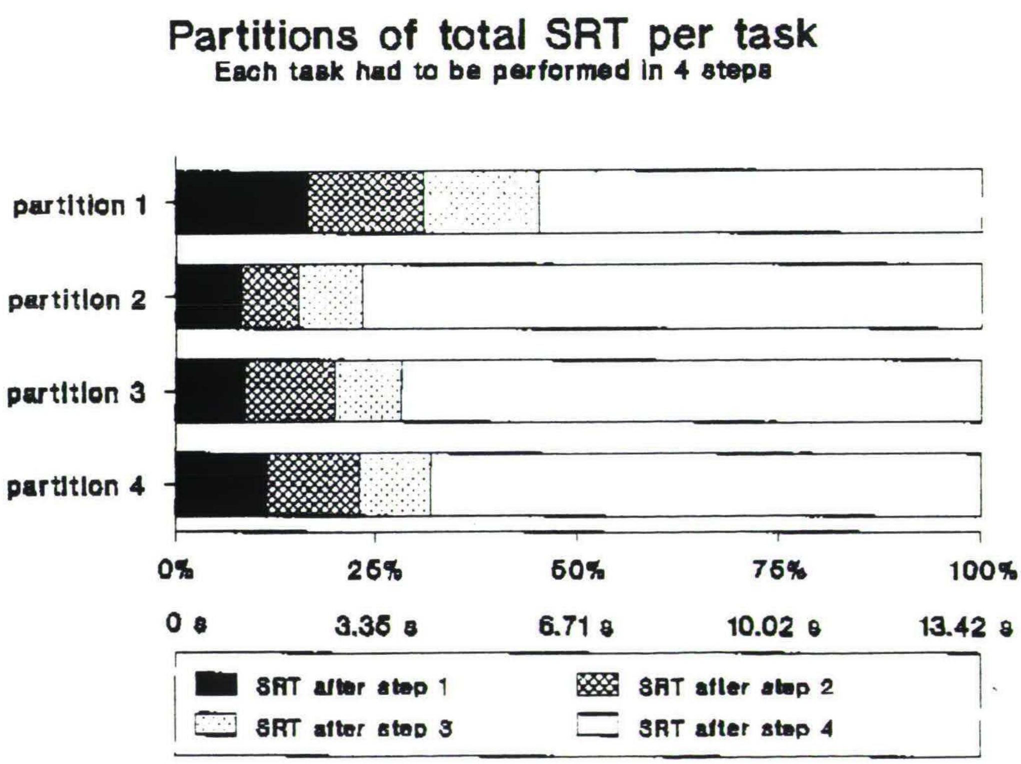


Figure 4

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